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Research Article

Chemistry in Civil Engineering-New Products and Applications

Abstract

The field of civil engineering is ever expanding where technology grows and advances at a very fast pace. Newer constructional materials are introduced every year to cater to these needs. There are certain naturally occurring cement types that have been found to bear many useful properties such as increased strength and workability and/or reduction in bleeding, segregation and heat of hydration. Examples of such naturally occurring cement include hydraulic lime and powdered surkhi. The paper delves on the various products and technologies that have been developed recently in the area of Civil Engineering. It consists of a discussion on the naturally occurring materials such as low cost paper bricks, bamboo, hydraulic lime and powdered surkhi. Furthermore, there are a host of industrial products with environment-friendly properties such as bamboo, insulated concrete, FRC, RPC, cellular reinforced concrete, diagrid, alternative materials of asbestos, insulated panels, engineered lumber and so on. With such bountiful gifts provide to mankind, it is essential to become more aware of their uses and applications. A detailed study on all of the above materials will facilitate the development of the various practical ways of their applications in the construction industry thus opening a plethora of opportunities. The paper delves on such products and technologies that have been developed recently in the area of Civil Engineering focussing primarily on the naturally occurring materials.

Introduction

Civil engineering is the oldest branch among all engineering branches. Its origin dates back to several centuries ago. Some of the earliest structures that were built include the pyramid, temples, houses and irrigation projects. From then to the present times, there have been immense changes in the techniques and materials that are used for the construction of buildings and structures. Also the diversity of construction projects have increased manifold and the time allotted for the construction process has decreased to degrees. Consequently, the complexities of the process have increased.

There are several break-through technologies such as the nanotechnology that can open wide avenues and give birth to products with many improved properties. Further, the industrial waste products can also be used for producing new products that can be used for construction. With more advanced recycling methods it can become possible to retain or enhance the properties these materials that were discarded as waste. It can help to increase the cost-effectiveness of the building to a great extent. Also, products that are considered hazardous but at the same time are extremely useful such as asbestos have been replaced by their alternatives serving similar purposes.

Naturally Occurring Materials

There are certain naturally occurring cement types that have been found to bear many useful properties such as increased strength and workability and/or reduction in bleeding, segregation and the heat of hydration. Examples of such naturally occurring cement include hydraulic lime and powdered surkhi.

Another construction material is the bamboo that is amongst the fastest growing plants in the world. It belongs to the grass family and is easy to cultivate. Moreover, it is easy to give designs on bamboo products thereby making it a cost-effective choice. It is also durable and lost lasting. Furthermore, it has been observed that the maximum tensile strength of certain varieties of bamboo is comparable to mild steel. Thus, it offers a good amount of resistance to tensile forces. Also, the energy released due to earthquakes gets absorbed in the joints of the bamboo products. It is due to this reason itself that the susceptibility of bamboo to fail in seismic zones is considerably low.

There are plenty of products that can be successfully developed from the industrial refuse as a product such as the paper bricks (Figure 1).

Paper bricks that are prepared from a mixture of cement and recycled paper mill waste in a proportion of 10% and 90% respectively. Thereafter, the mixture is blended and molded into various shapes followed by exposure to sunlight. The normal bricks are about double

Figure 1: Paper bricks [1].

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in cost and carry more weight as compared to the bricks which is made out of the recycled materials [1].

In such regions of the world that have deficiency in supply of materials it is extremely beneficial to use these economical and efficient bricks. Research is being carried out to develop a waterproof coating for the bricks. Once developed, it will enhance the workability and efficiency of the bricks since they can be used on exteriors of housing and deceiving the materials effectiveness in disaster prone areas [1].

Hydraulic Lime and Cement Varieties

In ancient times, lime (Calcium Oxide) was used as an adhesive or binding medium for masonry. Under the application of water, it is the property of lime to hydrate, set and eventually harden. Therefore, it is known as water lime or hydraulic lime. It is resistant to saltiness and frost and bears adequate compressive and a good degree of flexural strength. Hydraulic limes bear a range of setting times and strength development. Therefore, in accordance to the situation the selection has to be custom-made.

Depending upon the composition and make-up of the cements, they acquire different properties. Certain cement varieties with special properties that are used for enhanced functionality includes the Rapid hardening or high early strength cement, Low heat cement, High alumina cement, Quick setting cement, Expanding cement, Super sulphated cement and Sulphate resisting cement. Not only this, when additional materials such as fibres are introduced in concrete its properties get improved sharply (Figure 2).

Latest Developments in Concrete and its Applications

Certain latest advancements in technology that enhance the construction of a building affecting its strength and durability have been discussed below.

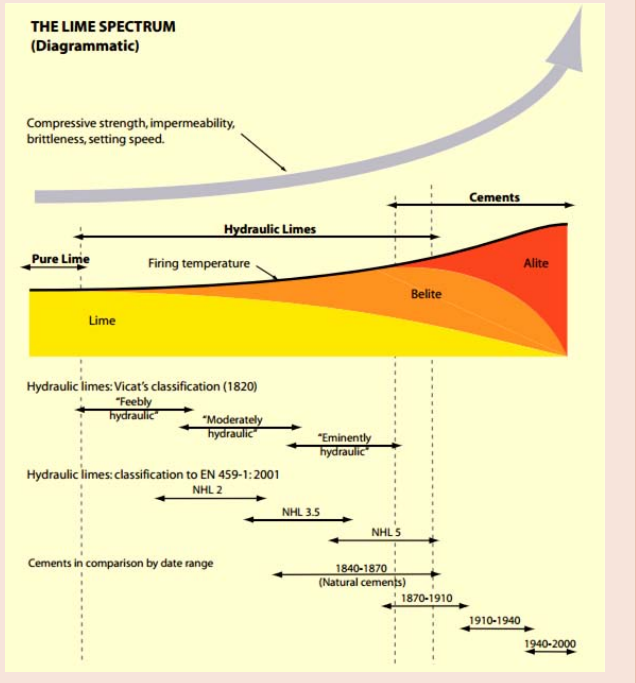

Figure 2: Diagrammatic representation of the Lime Spectrum (Brocklebank, 2006).

Insulated concrete forms

The Insulated Concrete Forms are lightweight, stackable and interlocking forms. It also incorporates interior and exterior insulation. ICFs can be used successfully for almost all exterior wall applications.

Reactive powder concrete (Rpc)

Special design techniques are employed by the modern time civil engineers to ensure stability and durability of a structure. Reactive Powder Concrete (RPC) is a technique that aims to facilitate optimal material utilization at the concrete manufacturing and production stage. It is a composite matter developed quite recently. The prime component of the reactive powder concrete is silica.

The compressive strength of the reactive powder concrete varies from two hundred MPa to eight hundred MPa. Reactive Powder Concrete (RPC) is a cost-effective replacement of the High-Performance Concrete (HPC) which is a simple mix with water and cement as the primary component. RPC consists of a blend of certain unique mineral components and some chemical admixtures. Due to this, the mixture gets several precise characteristics. Like the way the uniqueness of HPC imparts a definite property to concrete similarly RPC gains distinct characters to its unique composition. With the help of a series of laboratory tests it has been proved that the performance of the Reactive Powder Concrete (RPC) outshines that of High-Performance Concrete (HPC). The components used to manufacture RPC includes very fine powders of silica, sand, cement, steel fibres, fume, quartz powder and super plasticizer. The coarse packing of the fine powder once it gets dried out is optimized to derive a very solid equation and matrix providing enhanced durability to the structure [2].

Fibre reinforced concrete (Frc)

The concrete type comprising of fibrous materials is said to be as the Fibre Reinforced Concrete (FRC). The purpose behind adding fibres is to enhance the structural integrity of the structure. In their crystalline structural packing, these fibres are short, discrete, uniformly distributed and have random orientations in space. There are numerous benefits of these fibres. For example, steel fibres have the ability to increase the structural strength of the structure thereby reducing the requirement of steel reinforcement. Besides this, it also brings improvements in the freeze thaw resistance of the concrete [3].

Other types of fibres that are used industrially include glass fibres, natural fibres and synthetic fibres. The fibres show distinct characteristics within the concrete [3].

It has been observed that the properties of FRC changes with the variations in concrete, its geometrical pattern as well as orientation. In the event of plastic shrinkage, there can be development of cracks in the structure. The function of these fibres embedded in concrete is to minimize and mitigate these cracking. They enhance the durability of the concrete by decreasing the width of the cracks [4].

To enhance the impact resistance of concrete Polypropylene and Nylon fibres are used. Also, the fibres can reduce the bleeding of the water since they possess the ability to decrease the permeability of the concrete and hence its strength. With time much advancement has taken place resulting in the development of newer varieties of fibre reinforced concrete. Cellulose fibres and waste carpet fibres are some examples [3].

Cellular lightweight concrete

Cellular Lightweight Concrete which is also termed as Autoclaved Aerated Concrete (ACC) or porous concrete is a precast construction material which has considerably low weight. Cellular Lightweight Concrete evolved in the mid-1920s by the Swedish architect and scientist Johan Axel Eriksson. It serves a variety of functions such as resistance towards fire and insulation from electricity and heat. Furthermore, another advantage of cellular lightweight concrete is that it can be installed with adequate ease and speed. It can be used for building both interior as well as exterior structural members [5].

Carbon-steel tubes are used to cut and separate the material into sections of required shapes after it has been appropriately sanded. Thin bed mortar used by cellular concrete materials has a thickness of about 0.125 inches which is lesser than that used by the regular mortar [5].

Due to the enhanced thermal-efficiency provided by the cellular concrete, the overall consumption of electricity on heating and cooling of the house gets reduced sufficiently. Moreover, owing to the light weight of the concrete it becomes a material of choice for building structures that fall under the seismic zones. Besides this, it is for the same reason that using cellular concrete helps to reduce the costs incurred for transportation and labour. The convenience offered to the workers reduces wastage during construction further leading to cost efficiency in the construction. However, the most significant advantage of the cellular lightweight concrete is that its production is entirely eco-friendly [5].

For the manufacture of cellular concrete natural aggregates such as quartz, sand, lime and trace elements of aluminium along with water is used. Manufacture of cellular concrete is on a rapid rise in the Asian countries like India and China. Whereas owing to sluggish growth and recession its growth in the European countries has slowed down [5].

Shotcrete Technology

Concrete or mortar is a primary ingredient used for building construction. Concrete is manually prepared on the site by mixing cement, sand, aggregates and water in suitable proportions and is used right after being made. Concrete is used for building walls, roofs, bridges, culverts, high rise structures and so on. A latest development in modern civil engineering is the advent of Shotcrete which is a special type of mortar used for building construction [6].

The advantage of shotcrete is that they bring out simultaneous processes of compaction and placement. Shotcrete is passed through a pipe and is then projected with a help of powerful nozzle onto the desired surface or floor pneumatically and at a very high speed. The nozzle can deposit the mortar on horizontal overhead as well as vertical structures. Therefore, as it has been pointed out earlier that both compaction as well as placement processes takes place simultaneously. The term shotcrete is used represent both wet as well dry mixing mortar editions [6].

Diagrid

Diagrid or diagonal grid is a structural steel structure comprising of a series of triangles that combine and lateral supports as one unit. This in turn brings stiffness and efficiency and makes the building lighter than a traditional high-rise building. The triangular crisscrossing steel members are connected at specially jointed nodes which act as mutual reinforcement. "They create an integral network across a building surface that braces against the floors, the wind, and the members above. With this exoskeleton in place, the designer can cut down on internal supports, saving on space and building materials, allowing naturally broad apertures, and providing greater flexibility for systems installation" (Portmanteau) (Figure 3).

Some notable examples where the diagrid system has been implemented include the Swiss Re Building, Lotte Super Tower, Skidmore, Owings & Merrill, and Hearst Tower and so on. Diagrids can be made using either steel or concrete. Durability of the concrete that is used for building construction can be achieved through a well proportionate mix of cement-water ratio, careful design of cement matrix and its microstructure which would also lead to the development of strength. Durable concrete with strengths in the range of 30-80 M Pa is appropriate for practical applications. This would ensure that the structures are durable, long-lived and eco-friendly [7].

High strength concrete comprising of higher cement and reduced water content develops strength at a rapid rate. However, these are unsuitable for structures materials since they develop cracks easily. It has been observed that there is a certain critical threshold level of water. On falling below this level, it becomes necessary to use high range water reducing agents (HRWR) which is an undesirable effect since it decreases the durability of the concrete [7]. The synergistic interaction between Portland cement, slag and chemical admixtures

Figure 3: Exterior of the Swiss Re Building, Foster & Partners [7].

formed by a careful mixing of slag fineness, water-adhesive ratio, cement level and a high range water reducing agent promote the development of durability in cement concrete. This concrete gives rise to a homogeneous, dense and crack-free microstructure [7]. Furthermore, it results in reduced heat of hydration, extremely less bleeding rate and nominal changes to setting time compared to the ordinary Portland cement. Also, it has been proved that such concretes can be designed to possess highly refined pore structure containing very low diffusivity and very high resistance to water and chloride ion penetration [7].

Smart Home Systems

Smart homes are modern residential systems that cater to the needs and requirements of the occupants and variations in the environment in an adaptive manner. Smart homes offer intelligent ambiance that are readily responsive and interactive dynamically [8].

To build a smart home it is a requisite to borrow the technological advancements from a variety of fields i.e. an integration of developments and technologies from various fields. However there are also certain challenges imposed here such as that faced when designing the smart home while taking into consideration the mannerisms and conditions of human interactions and requirements. Also it has to be given due consideration that the interaction among the different components of the smart home takes place in a reliable, safe and seamless manner. To satisfy all these requirements it becomes a necessity to imbibe knowledge and guidance from a host of subjects ranging from technology to social sciences. Social sciences and humanity subjects will help understand the human nature, needs and requirements. Therefore, it can be seen that the nature of research and development efforts needed to realize smart homes takes a multi-disciplinary approach in order to render it suitability for the general public [8].

There are numerous applications served by the smart homes such as monitoring and control of appliances and devices, security, tele-medicine, recreation of the inhabitants, location based services, care for children and the elder member of family etc. There are a variety of services that can be offered by the smart homes and their degree of complexity and sophistication depends upon the technology used and its advancement [8].

Asbestos and its Eco-Friendly Alternatives

Introduction

Asbestos finds its major application in the cement and building construction sector. Building engineers, building material products manufacturers, cement plant production workers, construction workers including insulators, boilermakers, laborers, steel/ironworkers, plumbers, steam fitters, plasterers, dry-wallers, cement and masonry workers, roofers, tile or linoleum installers, carpenters, High Voltage Alternating Current(HVAC) mechanics and welders all use asbestos products in everyday life.

Chemically, asbestos minerals are silicate compounds i.e. they contain atoms of silicon and oxygen in their molecular structure [9]. Asbestos is a useful and popular material owing to its strength, durability and non-combustibility making it fit for wide usage in the construction industry. Also it is fire proof and has good electrical resistivity. Asbestos may be present in floor tiles. However in such a tightly bound state it poses no serious health risk. Asbestos is hazardous in case fibres are present in granular form in the air that people breathe (Figure 4).

Figure 4: Asbestos. (Image credit: www.mesotheliomatreatmentcenters.org).

However, asbestos exposure can pose serious health hazards to the users. It is a cause for asbestosis, mesothelioma, pleural plaques and lung cancer. Due to such a dangerous nature of asbestos, it has been banned in many states such as Australia, France, and Brazil, etc.

A necessary requirement for Amended Asbestos Regulations [10], is the inclusion of information to customers (downstream users) about health risks and proper procedures pertaining to asbestos usage. Despite providing information on proper procedures, dangerous unhealthy practices like high speed dry cutting and sanding do take place in asbestos firms. Hence sheet breakage and abrasion between sheets during manual unloading results in asbestos exposure.

One major safety improvement is the installation of 'automated asbestos bag openers' that led to dramatic reduction in fibre levels in the raw material area of the plant. Also engineering solutions are more expensive than PPE.

Chrysotile consumption by manufacturers from all around the world has come down drastically due to substitution programmes and plant closures.

An ideal substitute to chrysolite asbestos fibre would have equivalent mechanical and chemical strength. But that might share its toxicity criteria as well.

Extensive researches have been done at leading United States universities upon the issue of carcinogenicity of synthetic fibres and the availability of safer substitutes.

Health risks have always been borne by labourers and building occupants, not those who take ultimate purchasing or production decision. So even though asbestos costs low, the actual risks incurred can't be left out. The full cost includes the expense of mitigating health risks due to asbestos inhalation. In order to encourage leading producers to switch over to non-asbestos products, the social costs need to be internalized.

Asbestos is of high degree utility and banning its manufacture was not possible before the alternatives of asbestos are found. Hence companies before closing manufacturing plants did extensive research

on the substitute products, costs of production and associated hazards.

Alternatives to asbestos for a-c water pipe

- Ductile iron pipe
- High density polyethylene(HDPE) pipe
- Metal wire reinforced concrete pipe
- Clay pipe for low pressure areas.

For interior building walls and ceilings, a no. of A-C sheet substitutes have been identified: fiber cement, brick etc.

Fiber cement sheet products: Asbestos is replaced by polyvinyl alcohol fibers or cellulose fibres or a mixture of both. These may also be combined with mica or wollastonite so as to develop or augment fire resistance.

Asbestos is also a known roofing material. To replace asbestos, lightweight concrete tiles can be used. Interestingly, such concrete tiles can be made in the farthest locations with the help of plant fibres and biomass like jute, hemp, sisal, palm nut, coconut oil and wood pulp.

Asbestos in plaster [11]

The asbestos fibres are quite strong and about 100-200 times thinner than human hair. Asbestos in plaster can be of 2 types-loosely bound fibre, firmly bound fibre. Experts agree that asbestos in plaster is harmless unless it is disturbed because upon exposure the fibres can be inhaled.

In 1970's asbestos products which were firmly bound were used for domestic applications. But times have changed and cellulose fibres have replaced them.

Loosely bound asbestos fibres are termed friable and found major uses for insulation within heater and stoves. However asbestos has been off the market and in that duration glass fibres replaced asbestos products.

Recent developments

Some eco-friendly products have been recently found which are expected to have equivalent performance standards as asbestos with minimal unfavorable environmental effects. Green alternatives to asbestos include the use of lcynene foam, cotton fiber and cellulose. It is expected that implementation of eco-friendly products can bring down annual energy costs in the American households by 25 %.

1. Cotton fiber is made from recycled batted material and treated to be fireproof.
2. A water based spray polyurethane foam, lcynene features no toxic components.

Researchers noted that cellulose fibres have been used in several industries without "significant concern" [12] (Figure 5).

Applications

These fibres have worked successfully in

- Stuccos/plasters
- Tile adhesives
- Joint fillers for plasterboards
- Emulsion paints

Bituminous products (Industrial Raw materials)

If these green alternatives function satisfactory and are cost effective from consumer's point of view we can expect usage of asbestos to further drop down in the building sector. This can be explained by a theory in micro-economics-'cross price elasticity of demand' (Figure 6).

New Materials for Panelling and Lamination

Structural insulated panels

Structural insulated panels are the high quality foam core panels that have lots of strength and are energy-efficient. Moreover, they are suitable for several building applications due to a high degree of compatibility (Figure 7).

Panellized construction

In this approach, the pre-engineered wall sections for a new residence are prepared in industrial conditions. It is then transported directly to the construction site and planted onto the required areas. It develops resistance to the weather conditions within a few days of construction. Panelized home manufacturers produce structural members of varying design and sizes (Figure 8).

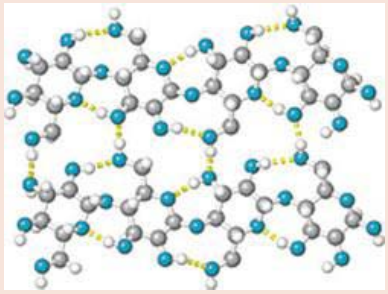

Figure 5: Cellulose fibres.

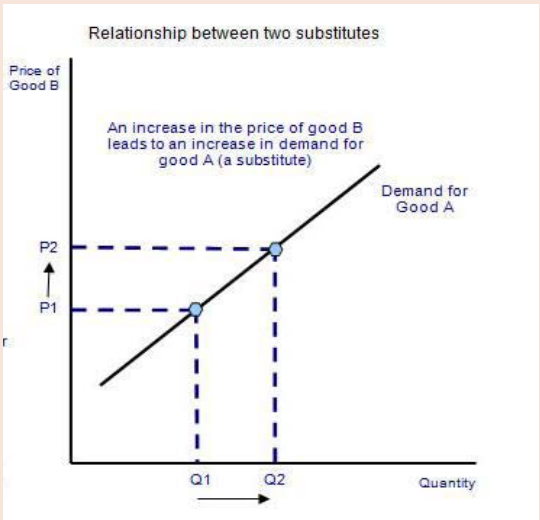

Figure 6: Graph for cross-elasticity of demand (Image credit: tutor2u).

Figure 7: Structured Insulated Panels on the exterior of a residence (Image credits-Murus Structural Insulating Panels).

Figure 8: Panellized house (Image credits-Prefab Friday).

Engineered lumber

Engineered wood or lumber structural members have considerably high performance. Furthermore, they are consistent, reliable and eco-friendly (Figure 9).

Laminate flooring

To imitate the feel and effect of the red wood, certain synthetic materials are blended with the natural ones resulting in the formation of the laminate flooring surfaces. This artificial material is cheaper than the natural hard wood floors. Laminate flooring can be installed with sufficient ease and convenience. It is manufactured from a wooden composite base and carries a photographic image of wood grain atop that imparts it the appearance of an actual hard wood floor [13] (Figure 10).

Other Technological Advancements in Civil Engineering

Recycling of scrap metals such as steel and aluminium

Steel is a widely used construction materials that has multifarious uses and applications in building construction. Latest innovations such as the Siemens-Martin or open hearth furnace have enabled successful and high quality recycling of the scrap metals. This was an improved technique that was developed from the Bessemer process and allowed greater control of the chemical compositions of the metal. Some of the most popular modern day methods of recycling steel include the use of a Basic Oxygen Furnace (BOF) and the Electric Arc Furnace (EAF).

Despite the fact that numerous sustainability technologies have been developed in the recent past, the absence of effective implementation hinder the success. Technology that makes sole usage of the renewable energy resources must be stressed upon. Buildings that are environmentally sensitive and function with minimum usage of energy are the key elements to sustainable living.

Determination of the construction quality

In the modern days there are numerous methods to determine the quality of construction that have been developed. For example, in the simple case of pavement engineering Ride Quality Parameter (RQP), Ground Penetrating Radar (GPR) and Falling Weight Deflect meters (FWD) are the three ways to adjudge the construction quality. The Ride Quality Parameter (RQP) calculates and determines the quality if ride on the pavement. Other techniques such as GPR and FWD are the non-destructive testing techniques that have the same aim [14].

Nano-technology in civil engineering

The technology that focuses on the development of products with

Figure 9: Large self-supporting wooden roof in Hannover, Germany (Bischoff, 2006).

Figure 10: Laminate flooring (http://www.designiv.com).

new or improved properties is known as the Nano-technology. Nano-technology is used to develop newer and better quality of concrete, steel, glass, paints and so on [15].

Nanotechnology offers vast amounts of improvements in the civil engineering field. It has helped improve the quality of and solved many issues with building materials such as concrete and steel. The use of nanotechnology has also helped created more efficient and sustainable materials such as self-cleaning and self-repairing concrete and windows. The use of coatings made from nanotechnology helps improve fire-resistance, corrosion protection, insulation, and countless other applications. Nanotechnology can even help improve the quality and availability of water.

Conclusion

Civil engineering is the oldest branch among all engineering branches. Its origin dates back to several centuries ago. Some of the earliest structures that were built include the pyramid, temples, houses and irrigation projects. From then to the present times, there have been immense changes in the techniques and materials that are used for the construction of buildings and structures. Also the diversity of construction projects have increased manifold and the time allotted for the construction process has decreased to degrees, the complexities of the process have increased.

The field of civil engineering is ever expanding where technology grows and advances at a very fast pace. As the requirements of man rise, the means and methods to realize those needs are developed at an equal rate if not higher. Newer constructional materials are introduced every year to cater to these needs. To carry out better and timely management of the construction processes, computers play an important role. The designs of the structure are carried out on very sophisticated software such as CAD, Catia, and Revit etc. Further, many new software with enhanced features and detail are being developed to serve the similar aim.

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